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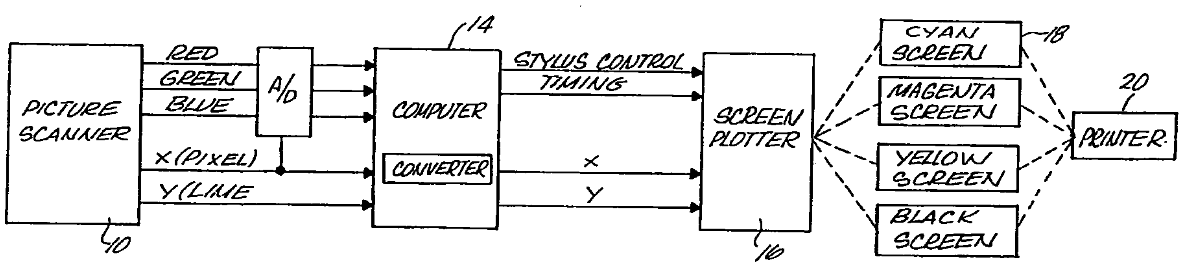

(57) Abstract

A method of generating a set of half-tone screens (18) for color printing (20) using a digital computer (14) and an x-y plotter (16), including the steps of generating and storing a separate and unique screen function matrix (26) for each of the half-tone screens (18), each matrix (26) comprising a set of light intensity level values in increments going from zero to a maximum, the sequence of numbers being a predetermined pattern that is different from each matrix (26), generating and storing a picture matrix of values representing the pixel portions and desired levels of color intensity of each basic color at the positions in the picture to be printed, creating each screen (18) by dividing each screen area into a plurality of cells (22), each cell (22) being formed as a binary matrix of elemental areas (24) that are selectively either clear or opaque, assigning one of said converted numerical values from each of said basic colors from said set to each of said cells (22) in the corresponding screens (18) being created; and setting the binary values for the elemental areas (24) within a cell (22) by comparing the converted intensity level value for the particular basic color with each of the values in the associated screen function matrix (26) the binary value for each elemental area (24) being set to one value or the other depending on whether the intensity level value is greater or less than the compared value stored in the cell function matrix (26).

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METHOD AND APPARATUS FOR PRODUCING HALF-TONE SEPARATIONS IN COLOR IMAGING

Background of the Invention

The present invention is directed to a method and apparatus for making color prints and more particularly for making half-tone screens for use in color printing.

In the conventional half-tone color reproduction process, an original color print or transparency is scanned by a photosensitive device that senses the variations in light intensity at each of the three primary color frequencies, namely, red, blue, and green. The average light intensity level for each primary color for each incremental area (pixel) of the scanned original is quantized and stored digitally. Alternatively, the digital values for red, green, and blue could be from other sources, such as by a programmed computer. This data is then processed to convert the values to the equivalent light intensity levels required to produce the same color from the three primary pigment colors, cyan, magenta, and yellow. It is also desirable to introduce a "black" component in addition to the three basic colors in the processed output data.

A set of four screens are produced, using a suitable plotter, from these four sets of values. Each screen, called a half-tone screen, is in the form of a grid. Depending on the printing process, the grid may

be in the form of physical openings or in the form of clear areas of a photographic negative. In the half-tone process, the ratio of the area of each opening or clear area to the surrounding opaque area is determined by the required color intensity for the particular pixel of the reproduced image. Each screen is then used to lay down a grid pattern of dots of the associated one of the three primary colors on the color print reproduction. The resulting color print is a reproduction of the original but composed of certain patterns of four dots of varying size. The human eye integrates these dot patterns into the various color tones and detail of the original.

One problem with the superposition of multiple grids is the resulting formation of interference bands or patterns, known as the Moiré effect. This effect is present whenever sets of parallel lines are superimposed at relative angles to each other. Where the sets of lines cross, they reinforce each other, producing dark bands in the picture. To minimize this effect in the color printing half-tone process, one technique is to place the superimposed grids at precise angles relative to each other, namely, 0 degrees for yellow, +15 degrees for cyan, -15 degrees for magenta, and +45 degrees for black. This solution and ways of implementing grid angle control are discussed in U.S. Patents 4,456,924 and 4,499,489. One problem with this technique is that a small deviation from these precise angles produces a noticeable Moiré effect. The Moiré effect is also minimized if screens are aligned at the same angle. However, this approach has not been considered practical since, when using the same screen geometry, any slight variation in lateral displacement changes the amount of overlap of the dots and this in turn changes the ratio of white area to color area, resulting in noticeable changes in color reproduction.

Summary of the Invention

The present invention is directed to an improved method of producing half-tone screens for color reproductions. The screens do not require relative angular rotation to avoid the Moiré effect. Instead, a rectilinear transposition of successive halftone screens is used to produce the color reproduction. The shape and relative position of dots in the different separations are chosen to minimize color shifts due to variations in registration at the printing stage. More accurate conversion from the RGB colors to the cyan, magenta, yellow, and black is possible due to a more regular pattern of superposition. In the past this conversion has required a geometrical analysis that is complex and uses some simplifying assumptions and approximations that introduce some deterioration of color quality. The present invention reduces the computational steps required to process the color data.

These and other advantages of the present invention are achieved, in brief, by first, for example, optically scanning the color original and measuring the light intensity in a sequence of pixel areas for each of the three primary color frequencies, or otherwise deriving color video data such as by graphic computations of a computer. Using a digital computer, the intensity levels for each pixel are then converted into a set of numerical values representing the corresponding intensity levels for each of the basic colors to be printed, for example, cyan, magenta, yellow, and black. A different screen function matrix is generated and stored in the computer memory for each of the four color screens being created for use in the color reproduction. Each screen function matrix comprises at least one set of all possible numerical intensity level values for the associated color. However, the pattern or positioning of the values within each matrix differs for each color in a predetermined manner.

Using a suitable x-y plotter, for example, each screen is created by dividing the screen area into a plurality of cells, each cell corresponding to one half-tone period. Each cell is formed by the plotter as a binary matrix of elemental areas, the plotter creating each elemental area in one of two states, e.g., clear or opaque. The screen function matrices have the same dimensions as the cell matrices, so that each elemental area in a cell has a corresponding intensity level value in the screen function matrix. Each cell of a picture screen is mapped to one or more particular pixel areas of the picture being reproduced. The binary state for each elemental area within a cell is determined by comparing the corresponding intensity level value in the screen function matrix with the stored intensity level values derived from the associated pixel areas.

Brief Description of the Drawings

For a better understanding of the invention, reference should be made to the accompanying drawings, wherein:

FIG. 1 is a block diagram of an embodiment of the invention;

FIG. 2 is a diagram showing the form of the data generated by the scanner from an original color picture being reproduced;

FIG. 3 is a diagram showing the form of the data after conversion for printing;

FIG. 4 is a diagram of screen cell as form by the plotter;

FIGS. 5A-D are sets of diagrams showing examples of the four screen function matrices;

FIGS. 6-9 are diagrams of screen cell patterns for each basic color at four different color intensities; and

FIG. 10 is a diagram showing the superimposed color positions.

Detailed Description

Referring to FIG.1 in detail, the numeral 10 indicates generally a scanner for receiving the original color picture that is to be reproduced. The original may be a color photograph, for example, either a print or transparency. The scanner may be of any well-known optical scanning device in which the picture is traversed in a raster type pattern by a photosensitive element that detects the level of reflected or transmitted light for each of the primary colors, red, green, and blue. These detected light intensity levels are converted to three electrical analog signals which are connected to an analog-to-digital (A/D) converter 12. In addition the scanner 10 generates two signals x and y which define the pixel position and the scanning line respectively of the scanning element as it moves relative to the picture. The A/D converter 12 is synchronized with the pixel position signal x so that a digital output is generated with each predetermined incremental advance of the scanning element. Thus, the picture is converted by the scanner 10 and A/D converter 12 into a series of picture elements (pixels), the average light intensity in each pixel for each of the three basic colors being a digital value, preferably on a scale of 0 to 1. While a scanner has been shown, the invention is not limited to any particular method of generating the digital color image data. For example, graphical information generated by a computer may be the source of the color image data.

The three digitized red, green, and blue output signals R, G and B, together with x and y position signals, are inputted to a digital computer 14. The computer stores the data in memory as a picture matrix, shown by the diagram of FIG. 2. The positions X_m,Y_n in the stored picture matrix correspond to the pixel positions of the scanned original. The three intensity

level values R, G, and B for each pixel are stored in the corresponding position in the picture matrix.

Once the data for the original picture is stored in the picture matrix, the computer processes the data to convert it to an equivalent set of intensity values for the primary printing colors cyan, magenta, and yellow. The mathematics for this conversion process is well known. See for example "Principles of Color Reproduction" by J.A.C. Yule, Wiley & Sons, 1967, Chapters 10 and 11. At the same time a fourth set of values for black are also preferably computed. The resulting data is stored in a print matrix, as shown in FIG.3, the four intensity level values C, M, Y, and K for each pixel being stored in the corresponding position x, y in the print matrix.

The print matrix data is used by the computer to provide control information to a plotter 16 which creates the four half-tone screens 18 required to make the color prints. The plotter is a conventional high resolution x-y plotter. Depending on the type of screen, the plotter printing element or stylus may be a laser beam, an ink jet, or other device capable of producing, on command, a contrasting dot in an elemental area on whatever medium the screen is being formed. The stylus can be positioned by x-y coordinate digital input signals at any selected incremental area within the plotting range. The screens may take a variety of forms depending on the particular printing process employed, such as a photographic negative. Once created, the screens are used in a conventional printer 20 to produce color prints.

The command signal for the stylus and the position control signals for the plotter are produced by the computer in the following manner. Referring to FIG. 4, the screen 18 being created is divided logically into cells 22, each cell corresponding to one half-tone period of the screen. The cell size (CS) depends on the

definition of the printing process. For example, printing on newsprint provides relatively poor definition and therefore the size of a cell can be relatively large. The cell size is also limited by the elemental size (ES) of the plotter stylus. The more plotter dots within a cell, the better the color range of the reproduced prints. If the cell size is the same as the size of an elemental area, for example, no half-tones can be reproduced. Preferably the cell size should be at least eight times the incremental area so that one cell includes sixty-four incremental areas. A plotter dot or elemental area, indicated at 24, has a physical dimension ES that is fixed by the minimum spacing resolution of the particular plotter used. The cell size CS is an integral multiple n of the plotter elemental area size ES. Each cell therefore consists of an n x n binary matrix of elemental areas or plotter dots 24. In the example shown, n = 8.

According to the present invention, the plotter is controlled by the computer to lay down a unique pattern of dots within each cell for each of the four half-tone screens needed to print a reproduction. The pattern varies from cell to cell to satisfy the half-tone or color intensity level requirement of each cell. At the same time the patterns are designed to minimize overlap of individual colors when the screens are superimposed. To this end, the computer stores a set of four screen function matrices 26. The dimensions of these matrices correspond to the dimensions of the cell matrix, namely, an n x n matrix, where n = CS/ES. Each position in the screen function matrices, therefore, has a corresponding plotter dot (elemental area) position 24 in a cell. The computer stores a different value at each position in a screen function matrix, taken from a set of values representing all the levels of color intensity on a scale of 0 to 1. The number of increments into which the intensity scale is divided is equal to the number of

positions in the matrix, namely, n x n. Referring to FIGS. 5A-D, four screen function matrices 26 are shown by way of example, one for each of the four basic colors, cyan, magenta, yellow, and black. In the figures, the numbers of the positions of each increment on the intensity scale are shown in place of the actual intensity level values.

Once the screen function matrices are computed and stored, the computer controls the plotter to advance the stylus from one elemental area to the next in a predetermined sequence. At each position, the computer issues a binary control signal to the stylus to either activate the stylus or not. The binary control signal is set by comparing the required color intensity level value for the particular half-tone period or cell as derived from the print matrix (see FIG. 3), with the intensity level value stored in the screen function matrix for the particular stylus position (elemental area) within the cell. For example, only if the required color intensity level is greater than the value derived from the screen function matrix will the computer activate the stylus (or not activate the stylus depending on the particular printing process). Figures 6-9 show the plotted cells for each color at four different levels of color intensity.

Every cell has at least one pixel of the scanned original, as stored in the computer, associated with it. There does not have to be any one-to-one correspondence between the pixels and the cells, although this special case simplifies an understanding of the invention. Mapping between the pixels and the cells is controlled by the computer so that a pixel value is assigned to each elemental area of the plotter. The same pixel value need not be assigned to every elemental area within a cell. Thus the mapping may vary depending on the relative size of the printed picture relative to the size of the original. For example, if a large

magnification of picture size is required, it is obvious that a single pixel of the original picture may be used to control the color intensity of a number of cells or half-tone periods. The number of pixels generated by the scanning process is to a degree independent of the number of cells in the printing process, the number of pixels being determined by the size (SS) of each pixel relative to the size of the original being scanned. Thus, as shown in FIG. 4, the cell boundaries do not necessarily coincide with the pixel boundaries, so that one cell may involve the intensity values from more than one of a group of adjacent pixels. Alternatively, the intensity value of a single pixel may be used to control the plotter in more than one cell.

Referring again to FIG. 5, a set of screen function matrices for the four colors, cyan, magenta, yellow, and black, is shown for a cell formed, for example, as an 8 x 8 binary matrix of plotter elemental areas. As noted, the dimensions of the binary matrix are fixed by the ratio of the required cell size to the size of the elemental area produced by the particular plotter. The intensity level numbers stored in each matrix are arranged in a predetermined pattern of positions which produce unique color patterns in the screen cells. Figures 6-9 illustrate the color patterns generated for each of the four colors at each of four color intensity levels, namely, at 12.5%, 37.5%, 50% and 81.8% color intensity, respectively.

The relationship between the screen function matrices for the four colors may be expressed as follows. Let V_1 (i,j) be the basic matrix for cyan, with i,j = 0,1, ... n. Assuming n is an integral multiple of four, then

(black) $V_4(i,j) = V_1(i, (j+n/2) \bmod n)$

(magenta) $V_2(i,j) = V_1((i+n/4) \bmod n, (j+n/4) \bmod n)$

(yellow) $V_3(i,j) = V_2(i, (j+n/2) \bmod n)$

where "mod n" stands for modulo n. If n is not a multiple of four, analogous transformations become more complex in their mathematical definitions.

A significant aspect of the present invention is that not only do the screen function matrices produce different patterns for each color, each cell for each color has two distinct and separate color areas, and these two color areas are located differently for each of the four colors. In the preferred embodiment shown, the arrangement of numbers in the screen function matrix shown in FIG. 5A for the color cyan produces two color areas in a screen cell (see FIGS. 6-9) that are approximately centered in two diagonal quadrants of the cell, while the arrangement of numbers in the screen function matrix shown in FIG. 5D for black produces two color areas approximately centered in the other two diagonal quadrants of the cell. The numbers in the function screen matrices for magenta and yellow respectively approximately center two color areas respectively at the centers of two adjacent boundaries of the cell, and at the center and one corner of the cell. When the screens are superimposed, the centers of the color areas for all four basic colors are arranged in the pattern shown in FIG. 10.

It will be noted that, with increasing color intensity, the pattern of numbers in the screen function matrices produces expanding areas of color in the cells by causing additional contiguous elemental areas to be added to each of the two color areas. In the case of magenta and yellow, because some of the color areas are centered on the boundary of the cell, the areas expand into the adjacent cells. Thus, although each cell has only two areas centered in the cell, some cells, at higher than the minimum color intensity level, may, in effect, have more than two color areas within the boundaries of the cell. It will be seen that, within a mosaic of cells of the four superimposed screens, the

color areas for cyan and yellow are located at equally-spaced interspersed positions along a first diagonal A, while the color areas for magenta and black are located at equally-spaced interspersed positions along a second parallel diagonal B. This arrangement insures the maximum spacing and minimum overlap between the colors in the pattern of color dots produced by the four screens. While a diagonal orientation of the color dots is preferred for best visual results, arrangement for the lines A and B at an arbitrary angle is equally possible. In the preceding discussion, the primary printing colors have been assigned to specific screen matrices by way of example. In practice, this assignment can be arbitrarily changed.

<u>What Is Claimed Is</u>:

1. Method of producing half-tone color reproductions using multiple screens for printing each of at least three basic colors, comprising the steps of:

scanning in a predetermined pattern the color original that is being reproduced;

sensing the light intensity of each of the three basic color frequencies in a sequence of pixel areas;

converting the level of light intensity at each color frequency for each pixel area scanned to a set of numerical values representing the desired levels of color intensity of each of the basic colors to be printed,

generating and storing a plurality of screen function matrices, one matrix for each screen, each matrix comprising a set of intensity level values in increments going from zero to maximum color intensity, the values being arranged in a different predetermined positional pattern for each matrix;

creating each screen by dividing each screen area into a plurality of cells, each cell being formed as a binary matrix of elemental areas that are selectively either clear or opaque, assigning one of said converted numerical values from each of said basic colors from said set to each of said cells in the corresponding screens being created; and

setting the binary values for the elemental areas within a cell by comparing the converted intensity level value for the particular basic color with each of the values in the associated screen function matrix, the binary value for each elemental area being set to one value or the other depending on whether the intensity level value is greater or less then the compared value stored in the cell function matrix.

2. The method of claim 1 wherein the position of a particular value within the screen function matrix determines the position of the elemental area in each cell whose binary value is set by that particular value.

3. The method of claim 2 wherein the positions of the values within a screen function matrix are fixed such that for any given intensity level value being compared, the resulting elemental areas of the same binary value are positioned in symmetrical groups of contiguous elemental areas when combined with adjacent cells of the resulting screen.

4. The method of claim 3 wherein the spacing between the groups within each screen is substantially equal.

5. The method of claim 4 wherein, with the screens superimposed, the spacing between groups associated with each of the different colors is substantially equal.

6. The method of claim 1 wherein the number of positions in the screen function matrix is equal to the number of elemental areas in a cell, there being one unique position in the screen function matrix for each elemental area of a cell.

7. The method of claim 1 wherein said step of converting includes converting the sensed light intensity values from each pixel into four basic colors to be printed.

8. The method of claim 7 wherein said step of generating and storing includes the steps of generating and storing four screen function matrices, the two lowest intensity values for a first one of the screen function matrices being approximately positioned in the center and one corner, for a second one of the screen function matrices at the centers of two adjacent edges, for a third one of the screen function matrices at the centers of two diagonal quadrants, and for a fourth one of the screen function matrices at the centers of the remaining two diagonal quadrants.

9. The method of claim 8 wherein said step of generating and storing each of said four matrices includes the step of positioning the values of successively higher light intensity levels in contiguous positions surrounding said two lowest intensity values.

10. The method of producing half-tone screens for use in color printing in which each screen controls the pattern for one basic color when the screens are superimposed, said method comprising the steps of:

generating and storing sets of numerical values, each set representing the desired levels of color intensity for each basic color in a respective one of a plurality of pixel areas of an image to be reproduced;

generating and storing a plurality of screen function matrices, one matrix for each screen, each matrix comprising a set of intensity level values in increments going from zero to maximum color intensity, the values being arranged in a different predetermined positional pattern for each matrix;

creating each screen by dividing each screen area into a plurality of cells, each cell being formed as a binary matrix of elemental areas that are selectively either clear or opaque, assigning at least

one set of values from said sets of numerical values to each of said cells; and

for each half-tone screen, comparing the numerical value in the assigned set that corresponds to the print color of the half-tone screen with each of the values in the associated screen function matrix, the binary value for each elemental area being set to one or the other depending on whether the intensity level value is greater or less than the compared value stored in the cell function matrix.

11. The method of claim 10 wherein the positions of the values within a screen function matrix are fixed such that for any given intensity level being compared, the resulting elemental areas of the same binary value are positioned in symmetrical groups of contiguous elemental areas when combined with adjacent cells of the resulting screen.

12. The method of claim 11 wherein the spacing between the groups within each screen is substantially equal.

13. The method of claim 12 wherein, with the screens superimposed, the spacing between groups associated with each of the different colors is substantially equal.

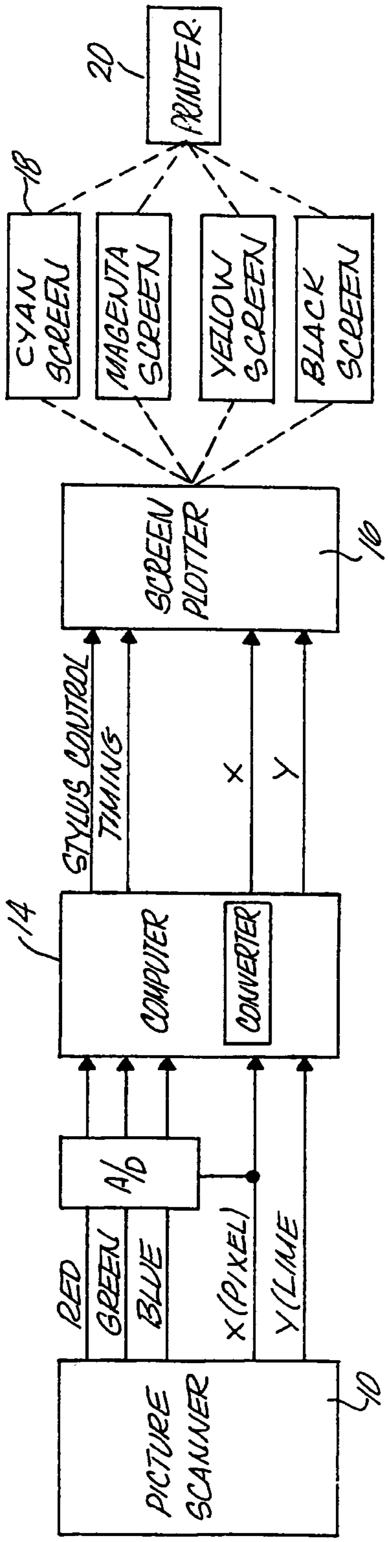
14. Apparatus for producing half-tone screens for use in color printing in which each screen controls the print pattern for one basic color when the screens are superimposed, said apparatus comprising:

means for generating and storing sets of numerical values, each set representing the desired levels of intensity for each basic color in a respective one of a plurality of pixel areas of an image to be reproduced;

means for storing a plurality of numerical screen function matrices, one matrix for each screen, each matrix comprising a set of intensity level values in increments going from zero to maximum color intensity, the values being arranged in a different predetermined positional pattern for each matrix;

means for plotting a screen including stylus means for creating a binary spot in each incremental area of the screen and means for positioning the stylus means at any incremental area; and

control means for the plotting means, said control means dividing the screen being plotted into a plurality of cells, each cell comprising a binary matrix of binary spots of the stylus, there being one spot in the binary matrix for each position in the screen function matrix, the control means setting the binary value of the stylus means by comparing the intensity level value in the corresponding position in the screen function matrix with the desired intensity level rom the means for generating and storing sets of numerical values.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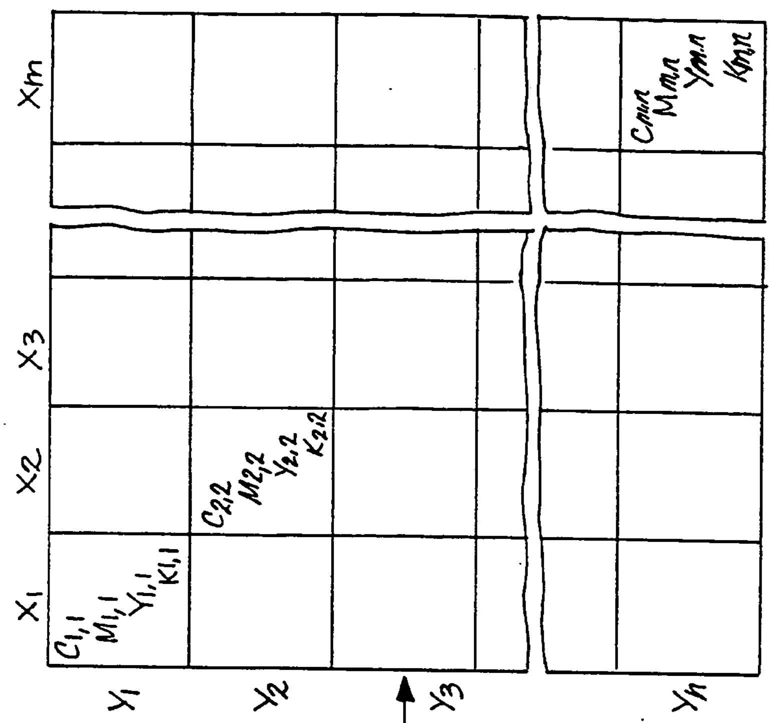
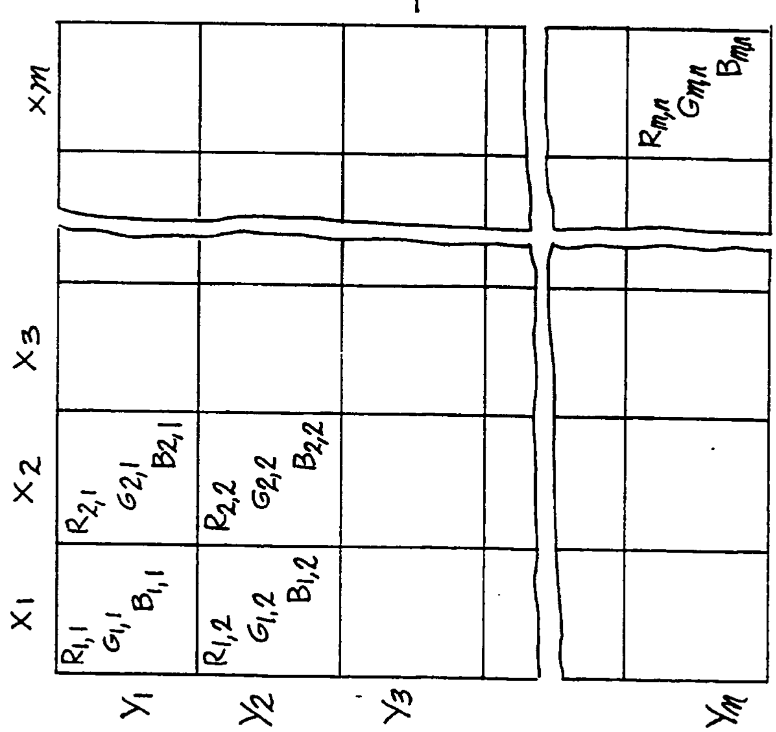
PRINTER
18
CYAN SCREEN
MAGENTA SCREEN
YELLOW SCREEN
BLACK SCREEN
SCREEN PLOTTER
STYLUS CONTROL
TIMING
X
Y
14
COMPUTER
CONVERTER
A/D
RED
GREEN
BLUE
X (PIXEL)
Y (LINE
PICTURE SCANNER

Fig. 1



PRINT MATRIX

Fig. 3



PICTURE MATRIX

Fig. 2

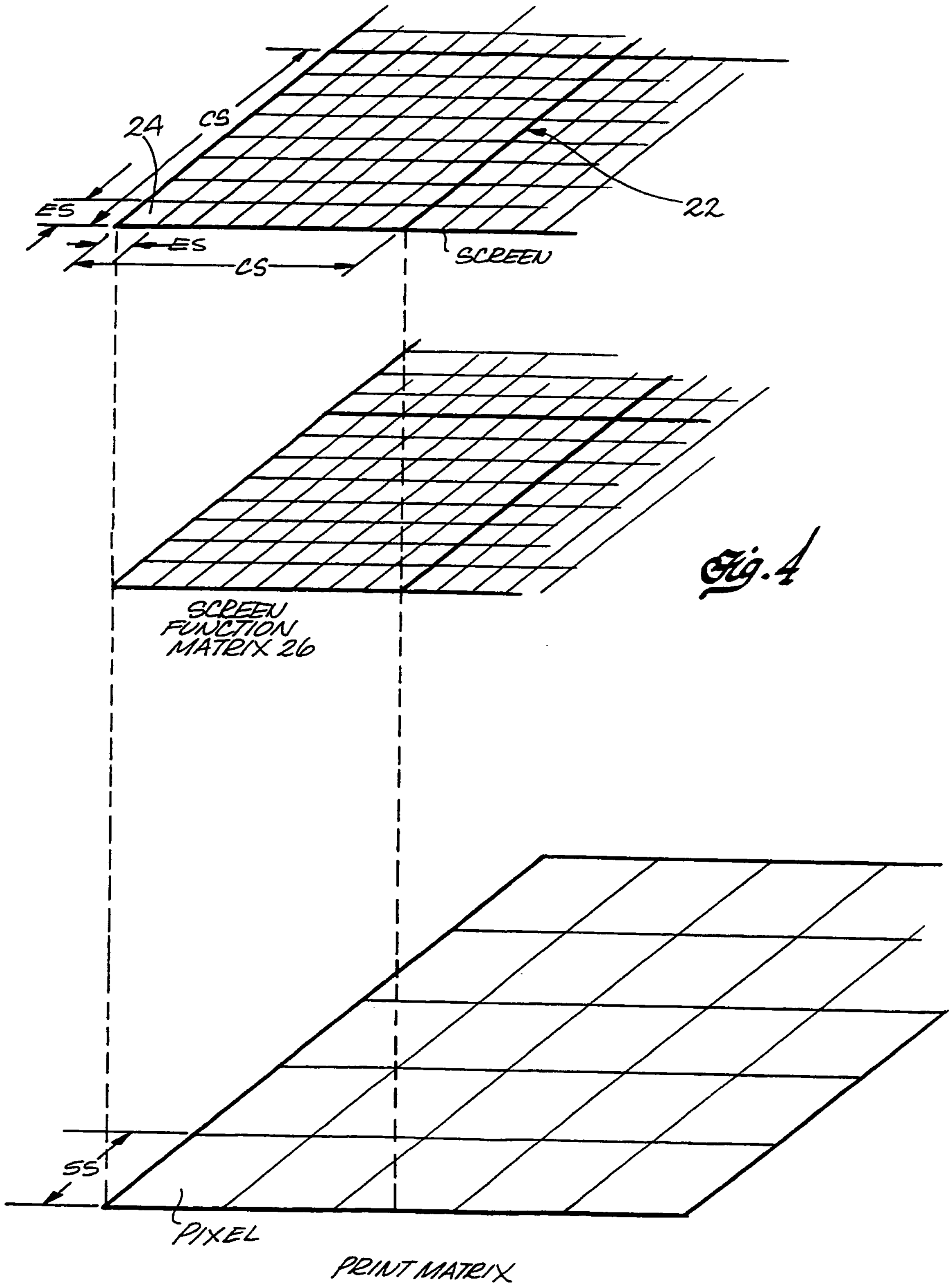

CS
24
ES
ES
CS
22
SCREEN
SCREEN
FUNCTION
MATRIX 26
SS
PIXEL
PRINT MATRIX

Fig. 4

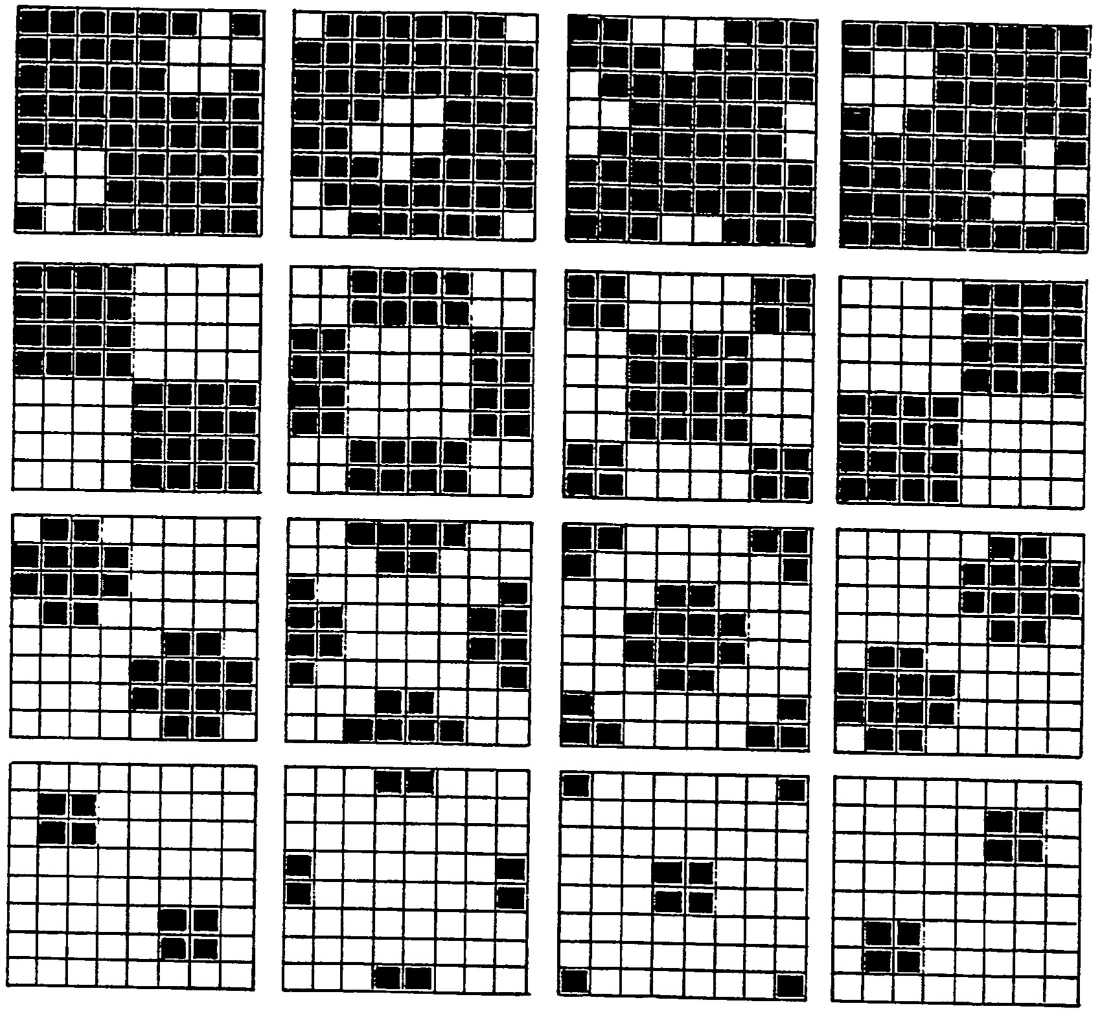


Fig. 6 12.5%

Fig. 7 37.5%

Fig. 8 50%

Fig. 9 81.25%

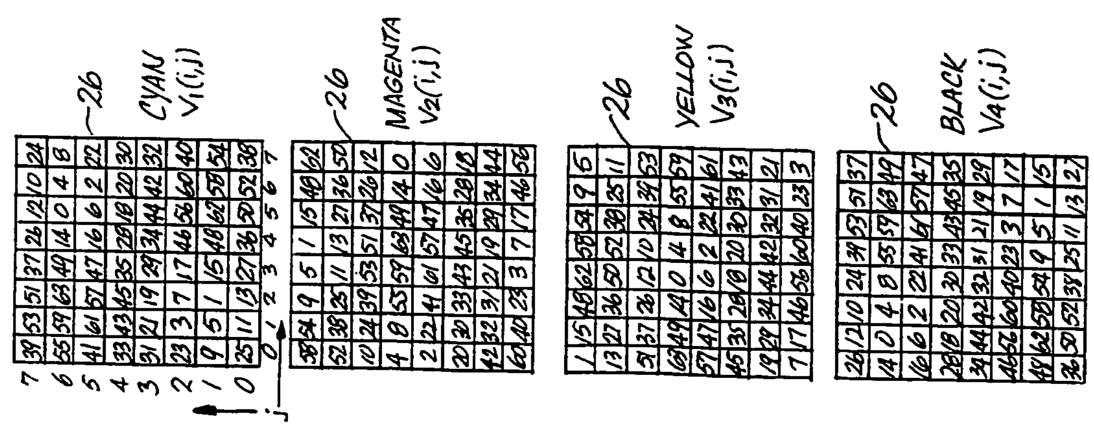


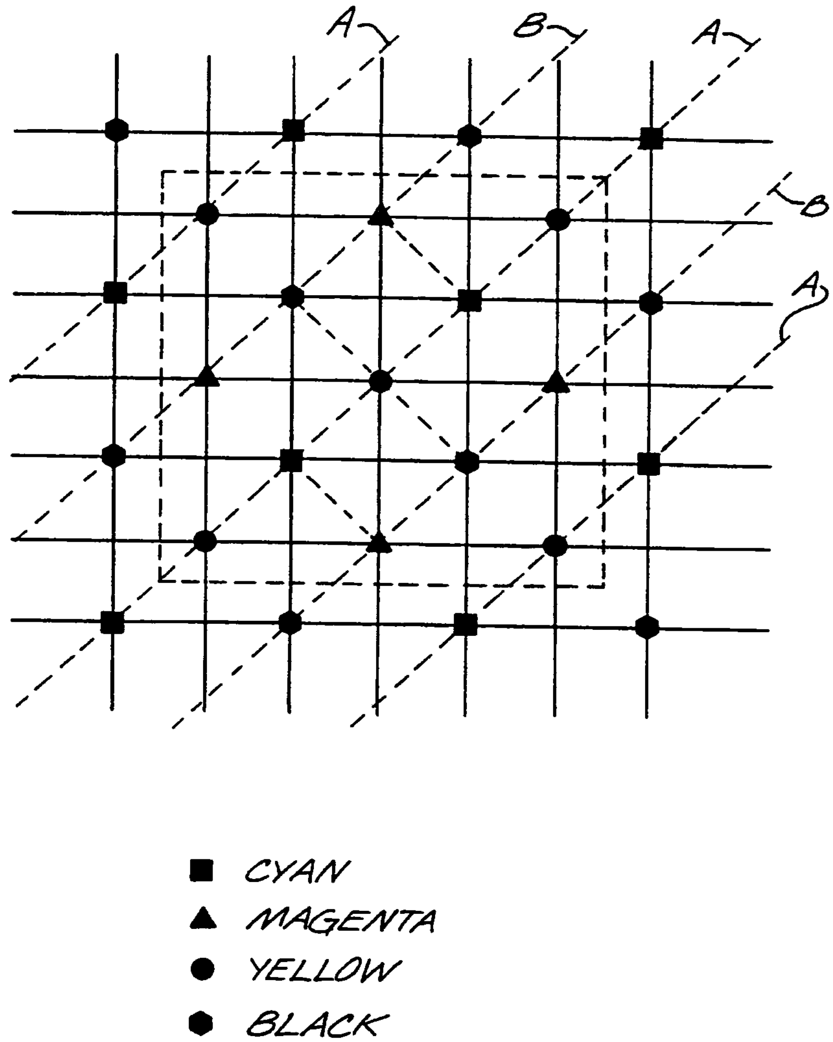
Fig. 5A

Fig. 5B

Fig. 5C

Fig. 5D

Fig. 10



INTERNATIONAL SEARCH REPORT

International Application No. PCT/US90/01248

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (5): H04N 1/46, 1/40

U.S. CL: 358/75,78, 454,457

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S.	358/75,78,80, 454,456,457,459,298

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US, A, 4,533,941 (KEANE ET AL) 06 August 1985. See columns 15,16 figures 1,2,14.	1-7, 10-14
Y	US, A, 4,456,924 (ROSENFELD) 26 June 1984. See columns 9-10.	14
A	US, A, 4,698,691 (SUZUKI ET AL) 06 October 1987.	
A	US, A, 4,768,101 (WEBB) 30 August 1988	
A	US, A, 4,680,625 (SHOJI ET AL) 14 July 1987	
A	US, A, 4,507,685 (KAWAMURA) 26 March 1985	
A	US, A, 4,752,822 (KAWAMURA) 21 July 1988	
A	US, A, 4,626,901 (TANIOKA) 02 December 1986	
A	US, A, 3,911,480 (BRUKER) 07 October 1975	

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
24 MAY 1990	27 JUL 1990
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